PLANETOLOGICAL IMPLICATIONS OF MASS LOSS FROM THE EARLY SUN

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The element lithium is observed to be underabundant in the Sun by a factor of ≈ 100. To account for this depletion, Boothroyd et al. (Ap. J., in press 1991) have proposed a model in which the Sun's zero-age-main-sequence mass was ≈ 1.1 $M_{\odot}$. If this is the explanation for the lithium depletion, then astronomical observations of F/G dwarfs in clusters suggest that the timescale for mass loss is ≈ 0.6 Gyr. Assuming this approximate timescale, we have investigated several planetological implications of the astrophysical model.

Since solar wind drag is unimportant for planets, conservation of angular momentum would require that they migrate outward by ≈ 10% during the hypothesized mass loss phase. Dynamical drag due to the enhanced solar wind would be important for any unaccreted residual planetesimals in orbits between the planets. Depending on size and location, the planetesimals could even migrate inward. We assume that the specific angular momentum of the wind is much less than that of the planetesimal. In this case a planetesimal of radius r, density ρ, and original semimajor axis a_o would migrate to a final semimajor axis given by

$$a^2 = a_o^2(M_o/M)^2 + (M/4\pi\rho r)[1 - (M_o/M)^3]$$

where M_o(M) is the original (final) solar mass. As an example, consider rocky planetesimals of density = 3 g cm^{-3} and radii < 1 km lying between the original orbits of Earth and Mars. These hypothetical planetesimals would enter the Earth/Moon sphere of influence during the mass loss phase, resulting in an enhanced impact rate in the inner Solar System. A similar effect would have occurred for any remaining low density icy planetesimals at locations within ≈ 7 AU. Other assumptions about the angular momentum content of the wind will give different migration formulae. However, in general there will be differential migration between planets and planetesimals. This would result in an enhanced impact rate during the postulated mass loss phase, assuming the existence of a sufficient supply of unaccreted planetesimals. Thus, in the context of the astronomical model and the assumption of residual planetesimals, a phenomenon similar to that of the late heavy bombardment would have occurred during the Sun's mass loss phase.

Climatically, the proposed astronomical model is consistent with the Earth not having undergone a moist or runaway greenhouse, even though the solar flux is extremely sensitive to mass ($\propto M^{6.75}$). The model is also consistent with the existence of liquid water on early Mars without postulating a massive CO_2 atmosphere plus (as yet) unmodeled effects (Kasting, Icarus, submitted 1991). Finally, the model is consistent with the approximate coincidence between the loss of liquid water on early Mars and the end of the late heavy bombardment.

C-4

GAPRA AND IDA IN FAMILIES

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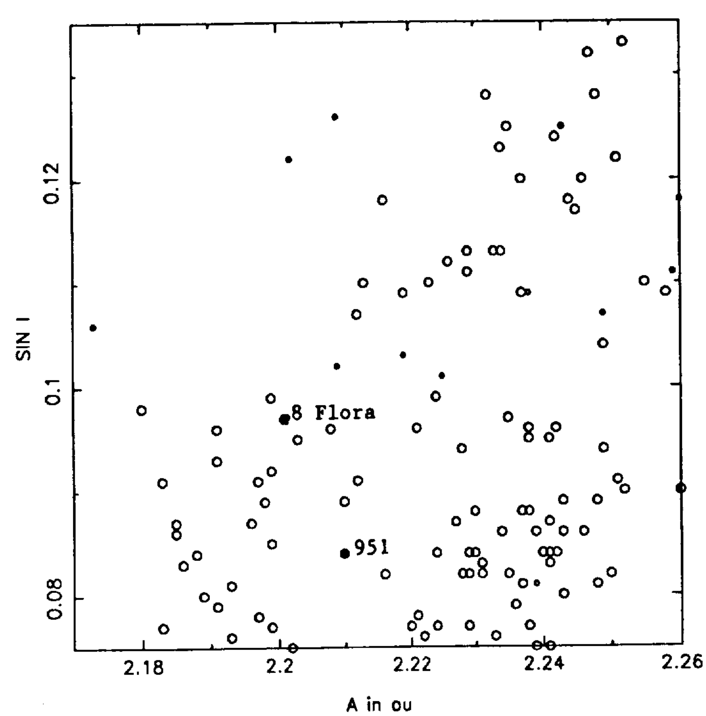
The Galileo flyby candidates 951 Gaspra and 243 Ida are both in families. The figure shows part of the Flora region near 8 Flora, a 141 km S. The remaining asteroids are all small, small enough to be cratering ejecta from Flora. The Flora region is the most complex region of the belt, consisting of adjacent and overlapping families. The cluster to the lower left of 8 Flora is family 189 which results from a cratering event, the cluster to the upper right is family 183, probably another cratering event. Gaspra has been assigned to family 189, but as can be seen it is not in the dense portion of the family and, due to the complexity of the region, cannot be guaranteed to have arisen from the same event. Because the spectrum of Gaspra is similar to Flora and because Gaspra is near to Flora, Gaspra is almost certainly a piece of 8 Flora, probably ejecta from a cratering event. 243 Ida belongs to the Koronis family and is located in the dense core of that family. The Koronis family results from a total breakup. The Galileo spacecraft will have the opportunity to sample fragments from two types of impact events.



WHAT MAKES A FAMILY RELIABLE?

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Several factors contribute to the perception of a family's reliability. Included are high population, a compact size in proper element space, high density, a low background of neighboring objects, neighboring families clearly separate, and reasonable geometry (no pretzels). If available, albedos, colors, spectra, and taxonomic classifications are important, particulary if the family's properties are in contrast to the background. The addition of newly discovered, higher numbered asteroids is an indicator of reliability. Seldom is a family lucky enough to satisfy all of the above properties. There are more families of low population than high population. Some families have larger extent than others and if they are not well populated they will be less evident. There are examples of crowded or overlapping families. Examples of multiple families from a single parent body are known. The background density of asteroids is different in different parts of the belt. The taxonomy may not be homogeneous in some families. Some considerations are more detailed. A family with a steep size distribution has more members to discover, but there appear to be genuine families with shallow size distributions which do not add many high numbered objects. The background asteroids may not be isolated, they may form low population clumps (unrecognized families) so that it is possible to mistakenly combine disparate clumps into one "family". Structure is common in the well populated families (commonly asymmetries) and it cannot be assumed that the less populated families lack structure. Among the less certain families, additional data will establish reliability or require reconsideration, but some cases (e. g., overlapping families) will always prove difficult.

The Unusual Lightcurve of 1990 TR

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Amor asteroids 1990 TR was monitored during 3 nights shortly after discovery. Obtained lightcurves did not reveal repetable two maxima and two minima. However, some features suggest periodicity and P = 6h 25m is determined. Individual and composite lightcurves are presented.

NEW FAMILIES OF ASTEROIDS; R.F. Wolfe, U.S. Geol. Survey, Flagstaff, AZ 86001

Since early in this century, many and often conflicting divisions of asteroids into families have been advanced (Hirayama, 1928; Brouwer, 1951; Arnold, 1969; Linblad and Southworth, 1971; Williams, 1979, 1989). The present study extends the work of J. G. Williams. Williams has linked asteroids into more than 100 families, using his proper elements, for about the first 2100 numbered asteroids and for Palomar-Leiden Survey (PLS) asteroids with one-month-arc orbits (Williams and Hierath, 1987).

The goal of the present study was to determine family membership of faint asteroids discovered by S. J. Bus in 1981 during the United Kingdom-Caltech Asteroid Survey (UCAS). This survey led to the determination of relatively precise orbits for about 1200 new faint asteroids. It was expected that examination of such a population of faint asteroids for family membership would shed considerable light on relative ages of families and on the collisional breakup process.

At present, multiple-opposition orbits have been calculated for about 6500 asteroids. The availability of this large number of precise orbits makes it possible to recognize and to study details of family structure more readily than ever before. Using osculating orbital elements from B.G. Marsden of the Minor Planet Center for numbered asteroids through number 4559 and for all multiple-opposition unnumbered objects, I calculated proper elements by the method of Williams (1969). In addition, I calculated proper elements from osculating elements of the UCAS asteroids. After removing all asteroids falling within Williams' family boundaries in semi-major axis, eccentricity, and inclination, I combined the remainder with all other non-family members for which proper elements had been calculated. From this sample, using both graphics and computer analysis, I have found over 30 new candidate families. Some of these families consist solely of faint PLS and UCAS asteroids.

The formation of a family in the asteroid belt by impact is the equivalent of the formation on a planet of an impact crater. Each family is the result of a discrete impact event. Collision of a small asteroid with a larger asteroid commonly breaks up the larger object into several smaller bodies that are moderately dispersed in orbital element phase space by the impulses acquired during the impact.

The Tiflis Family was the first group of Mars crossers found in this study. (753) Tiflis itself is a shallow, Mars-crossing asteroid with a crossing depth of -.015. From impulses acquired in the collisional breakup of the parent, most of the smaller fragments have become deeper Mars crossers. Their orbital elements, as would be expected, appear to have been further dispersed by Mars encounter. Thus, there is a greater spread in proper elements, particularly inclination, than in non-planet-crossing families. The fact that we can still recognize this family indicates that it must be fairly young, because encounter with Mars should lead to still larger dispersion of orbital elements in a period of on the order of a few hundred million years.

Asteroids such as Tiflis, which just graze the orbit of Mars, are an important source of deep Mars crossers. Most of these very shallow Mars crossers are found in a relatively stable region of proper-element space remote from resonances. They have very long dynamical lifetimes, and they may have occupied shallow crossing orbits since the time of heavy bombardment. Collisions with these shallow-crossing asteroids probably are a significant source not only of deeper Mars crossers but also of Earth-crossing asteroids, because further Mars encounters can deliver asteroids to Earth-crossing orbits. In the Tiflis Family, we see evidence for the first stages of injection of collision fragments into deeper crossing orbits. Because of the importance of this Mars-crossing family, emphasis has been placed on locating others. One of the groups subsequently discovered is composed of high-inclination asteroids.

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VELOCITY DISTRIBUTIONS OF H AND OH PRODUCED THROUGH SOLAR PHOTODISSOCIATION OF H_2O, C. Y. Robert Wu, F. Z. Chen, and D. L. Judge, Space Sciences Center and Department of Physics, University of Southern California, Los Angeles, CA 90089-1341

This paper presents the calculated velocity distributions of atomic hydrogen and hydroxyl radical produced through solar photodissociation of gaseous H_2O molecules. The relevant processes that produce H and OH photofragments in the ground and excited states are:

$$H_2O + h\nu \rightarrow H + OH \quad (1)$$
$$\rightarrow 2H + O \quad (2)$$
$$\rightarrow H + OH^+ + e \quad (3)$$
$$\rightarrow H^+ + OH + e \quad (4)$$

In his pioneering work, Festou[1] only treated process (1) and only considered the first absorption band of H_2O in the 1360-1860Å region and the absorption at the H Ly-α line. Recently, Crovisier[2] improved the model calculation by including the vibrational energy distributions of the ground state OH fragment.

In the present work we have extended the wavelength region of the photodissociation precesses and have also included processes (2) through (4). The calculation has been carried out using (a) the most recent available absolute partial cross sections for the production of H and OH through photodissociation of H_2O from its absorption onset throughout the EUV region[3], (b) the newly available vibrational[2] and rotational[4] energy distributions of both the excited[4] and ground[2,4] state OH photofragments, and (c) the integrated solar flux in 10Å increments from 500 to 1860Å in the "continuum" regions and the specific wavelength and flux at the bright solar lines, e.g., the H Ly-α, -β, -γ, O VI, C III, He I, etc. Since there are undetected neutral products with quantum yield as high as 0.4 in the 600-830Å region[3] that have not yet been included in the calculation, our present work represents a lower bound. The results, however, show that the hydrogen atoms produced exhibit multiple velocity groups centered at 14, 18, 30, 35, 37, 40 km/s and higher. Since most of the current cometary modeling uses a single velocity of 20 km/s associated with the photodissociation of H_2O. The present results may be useful in interpreting the "many peaks" observed in the velocity distributions of the H Ly-α[5] and Hα[6] of comet Halley.

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Formation of the Leonid Meteor Stream and Storm

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It is well known that some meteor showers display a very high level of activity at certain times, the most famous being the Leonid shower with very spectacular displays at roughly 33 year intervals. This period being also the period of the parent comet of the stream, Comet Tempel-Tuttle. An investigation of the geometry of the comet and the Earth at the time of each high activity occurrence by Yeomans (1981) suggests that most of the meteoroids are found outside the cometary orbit and lagging the comet.

In this paper we simulate the formation process of such a stream by numerically integrating the orbits of dust particles ejected from the comet and moving under the influence of gravity and radiation pressure. The intersection of these dust particles with the Earth is also considered and it is concluded that about 12% of the ejected particles may be observed and that of those observable, 60% will be outside the cometary orbit and behind the comet.

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NITROGEN CONSTRAINTS ON SOLAR NEBULA CHEMISTRY

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The isotopic, elemental and molecular abundances observed in comets potentially contain vital information about the prevailing conditions in the outermost parts of the early solar nebula. Ammonia abundances have been inferred from NH_2 production rates derived for a small sample of comets (Wyckoff, Tegler, Engel 1991b). The N_2/NH_3 ratio has been estimated for comet Halley. An inventory of nitrogen compounds in comet Halley indicates a large depletion of elemental nitrogen in the cometary volatiles, and that most of the nitrogen is carried by NH_2 and CN containing compounds (Wyckoff, Tegler and Engel 1991a). The nitrogen deficiency can probably be explained by fractionation during condensation of volatiles in the outer solar nebula or by subsequent thermal diffusion as the comet nucleus orbits the sun, or both. The elemental nitrogen depletion in comet Halley can be used to correct the observed N_2/NH_3 coma abundance ratio to the gas-phase value in the comet-forming region of the solar nebula. This ratio is found to be significantly *smaller* than the initial N_2/NH_3 abundance generally assumed in models of solar nebula chemistry. On the other hand, this corrected N_2/NH_3 ratio is *comparable* to that observed in star-forming regions in dense molecular clouds (Womack, Wyckoff and Ziurys 1991). Thus contrary to general belief, $N_2 \sim NH_3$ in both the early solar nebula and the present-day star-forming regions.

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